

EPRI Results Summary:

A Case Study Assessment of Trace Metal Atmospheric Emissions and Their Aquatic Impacts in the San Juan River Basin

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EPRI San Juan Basin Project Goals

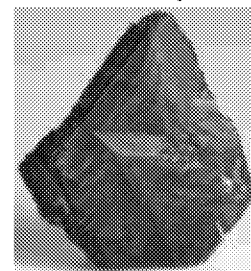
- Integrated assessment of atmospheric inputs and watershed concentrations of trace metals
- Identification of mercury contributions to fish tissue by source category
- Accounting for accumulation over time, slow movement of substances
- Reasonable projections of future actions and their outcomes
- *Outcomes sought:*
 - Time series
 - Fish tissue mercury levels in top predators, by source, for a range of source scenarios
 - Water column selenium, arsenic from 3 nearby sources
 - Source attribution: Fish tissue mercury changes
- *Not* carrying out assessment vs. wildlife criteria (ERA). Results transferred to other research groups for use in assessments.

Key Points About Mercury Dynamics



- Complex transitions between inorganic, organic forms
 - In atmosphere (after emission):
 - Most emissions are elemental mercury = GEM form
 - Oxidation-reduction reactions between elemental and oxidized = ionic = divalent = GOM (“gaseous oxidized mercury”) form
 - Removal from atmosphere:
 - Elemental Hg: nearly insoluble in water (precipitation), so transported very long distances (continental), may oxidize to GOM
 - Oxidized Hg: soluble in precipitation, “washes out” of atmosphere, tends to deposit closer to sources
 - Upon reaching the surface/surface waters:
 - Divalent mercury is reactive, small portion converted to organic form (mostly “methylmercury” = monomethylmercuric chloride)
 - Methylmercury taken up by aquatic organisms, food web, bioaccumulates to x1000s in concentration

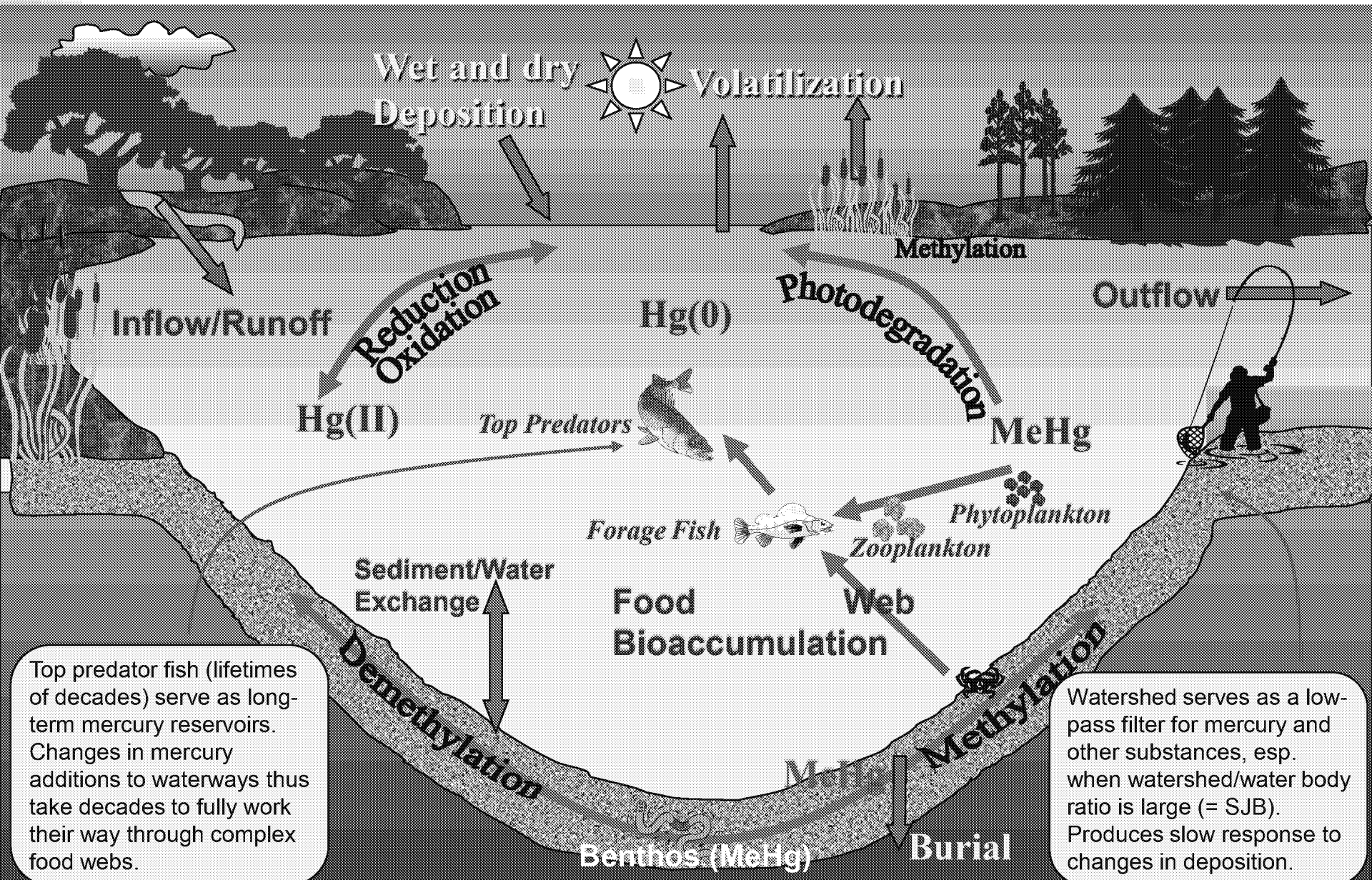
*Cinnabar ore
(mercuric
sulfide)*



monomethylmercury



The Complex Aquatic Dynamics of Mercury



Modeling Tools Used in the Analysis

GEOS-Chem → CMAQ-APT

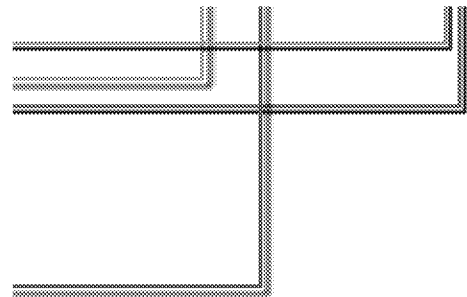
- **GEOS-Chem:** A global-scale model, developed by NASA and Harvard
- **CMAQ-APT:** A regional/local-scale air quality transport/chemistry model, developed by EPA and EPRI
- **Input:** Atmospheric emissions data from point and non-point sources, meteorological data
- **Output:** Wet & dry atmospheric deposition of pollutants



Watershed Analysis Risk Management Framework (WARMF)

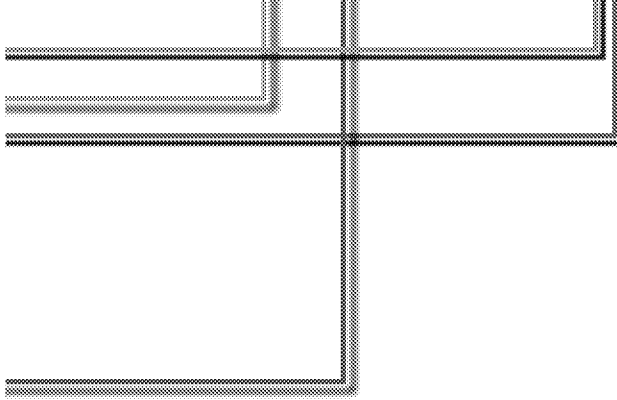
- A hydrology/water quality model, developed by Systech/EPRI
- Handles aquatic chemistry/biochemistry of mercury, other constituents
- **Input:** Wet & dry atmospheric deposition, meteorology, topography, soil data, point sources, diversions
- **Output:** Water quality (mercury, selenium, and arsenic concentrations), stream flow, concentrations of mercury in fish

EPRI Air-Watershed Analysis

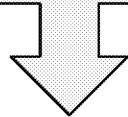


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* Emissions of Hg, As, and Se are "tagged" from the 3 power plants to track the separate contributions of those sources

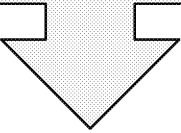


**4 air emission
scenarios with
sources
tagged
throughout**



*

* *Emissions of Hg, As, and Se are "tagged" from the 3 power plants to track the separate contributions of those sources*



**6 watershed scenarios
to distinguish source
contributions to tissue
concs (Hg), water
column concs (Se, As)**

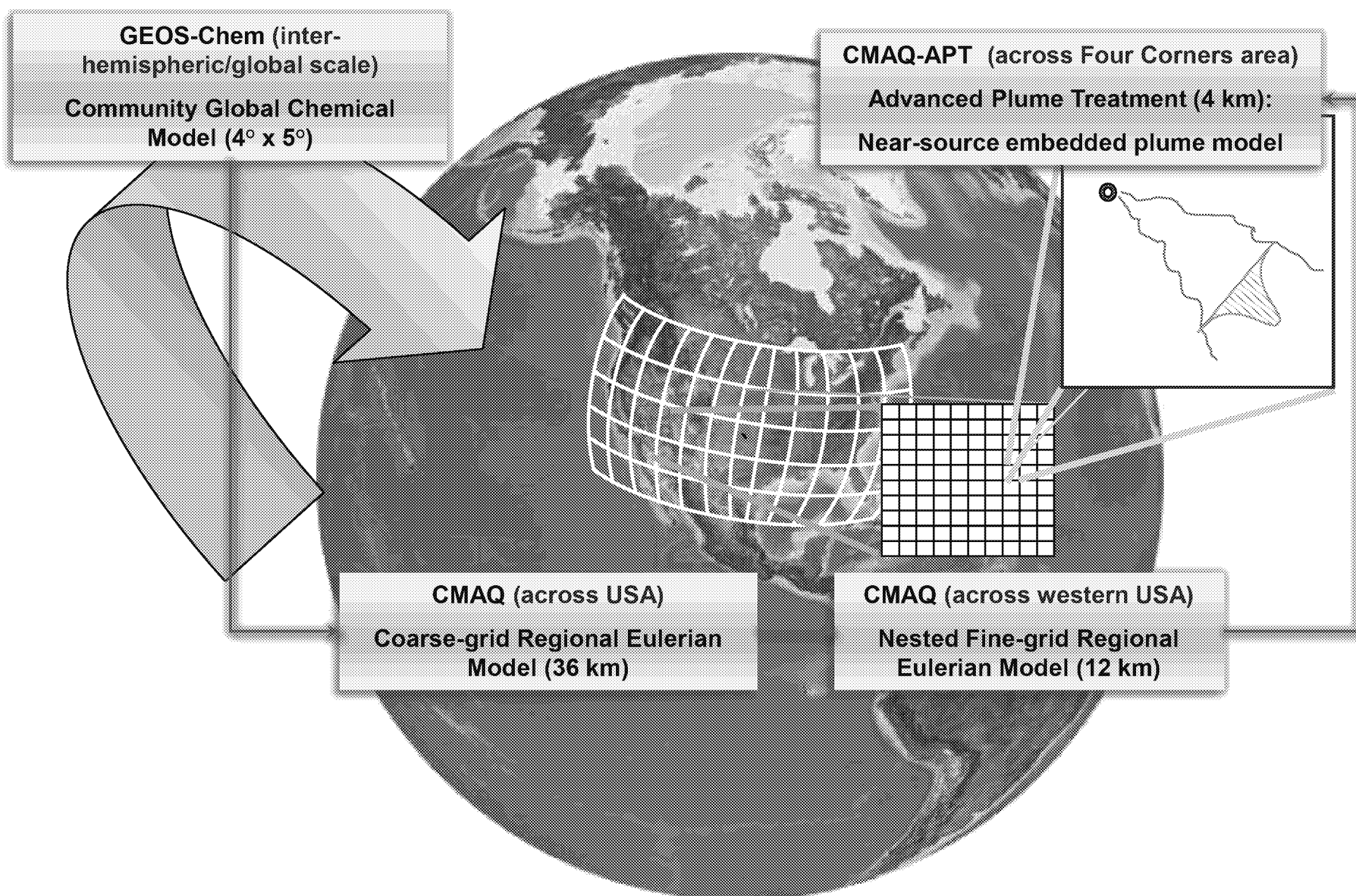
Atmospheric Emissions and Deposition Modeling

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ENVIRON

Historical and Future Atmospheric Deposition Record for Watershed Scenarios

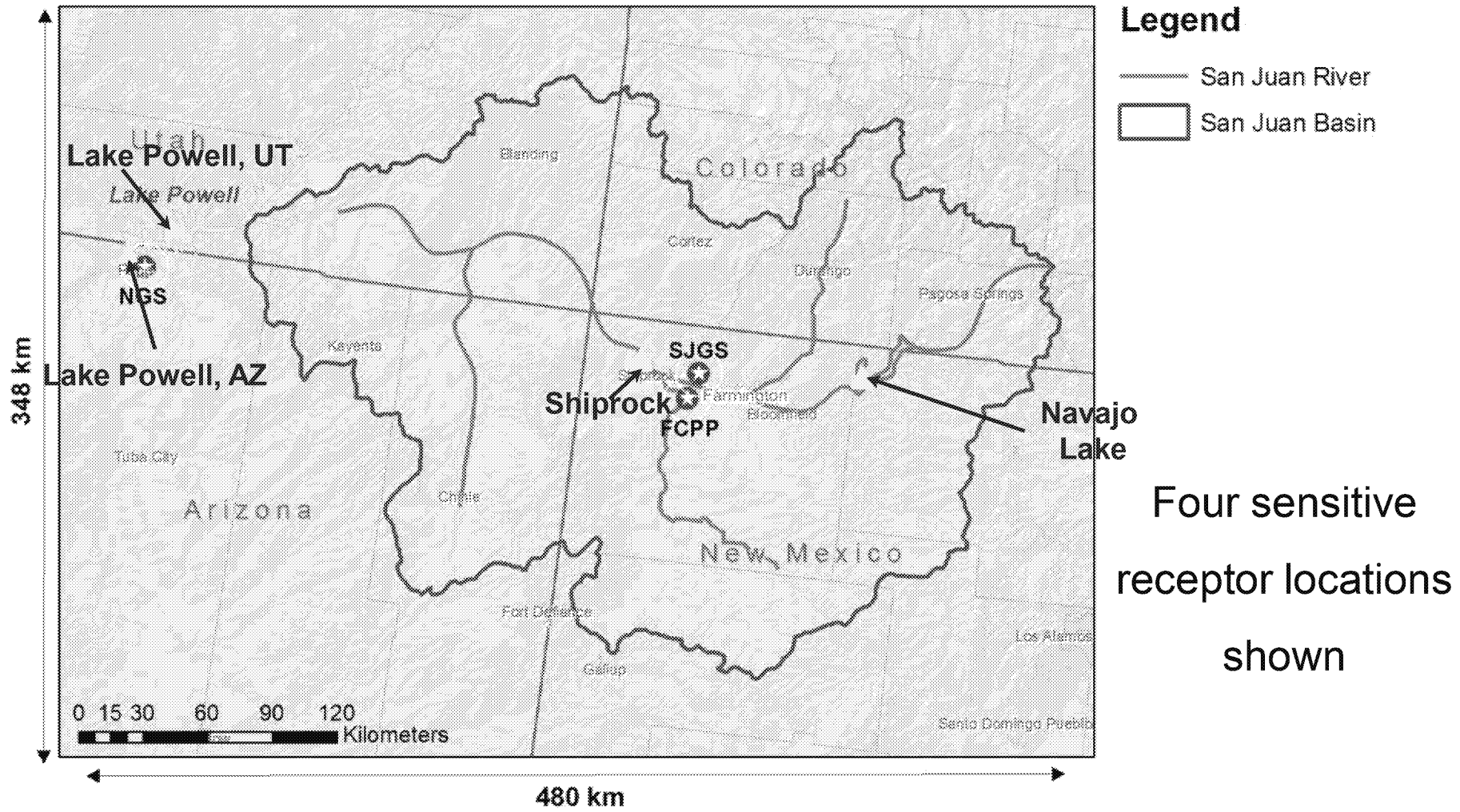
- Time Period: 1990 – 2074
- Annual mercury deposition calculated due to temporally varying emissions from:
 - Four Corners Power Plant (FCPP)
 - Navajo Generating Station (NGS)
 - San Juan Generating Station (SJGS)
 - Other sources in Four Corners domain
 - Other sources in USA
 - China sources
 - Other global sources
- Annual arsenic and selenium deposition calculated due to temporally varying emissions from FCPP, NGS and SJGS

Air Modeling: Global, Regional and Local Scale



Multi-scale modeling conducted due to observational evidence of long-range transport of Hg

Local-scale Air Modeling Domain



Air Source Emissions Modeling Scenarios

❖ Approach

- ❑ Source emissions of Hg, Se, As are “tagged” to allow contribution of each to be identified in deposition to the watershed
- ❑ Allows 4 air source scenarios to provide input to many watershed scenarios

❖ Air source emissions scenarios

- ❑ Baseline (pre-MATS) scenario
 - Source emissions are set to represent the period from 1990* to present
 - Used for build-up of slow-circulating constituents in the watershed
- ❑ Post-MATS scenario
 - Represents post-2016 period (2014 in case of FCPP)
- ❑ High China growth scenario (2050 A2 case) **
 - Chinese elemental Hg emissions increase 2032–2050 → increasing China deposition in U.S.
- ❑ Low China growth scenario (2050 B2 case) **
 - Chinese elemental Hg emissions decrease 2032–2050 → declining China deposition

* 1990 is start of watershed simulations

** China scenarios apply only to mercury

Changes in Local Power Plant Emissions

❑ Four Corners Power Plant

- 1990 – 2013: 5 units operational
 - Hg = 518 lb/yr, As = 76 lb/yr, Se = 1412 lb/yr
 - 3 units retired at the end of 2013
- 2014 – 2041: 2 units operational
 - Hg = 102 lb/yr, As = 50 lb/yr, Se = 425 lb/yr
- 2042 – 2074: FCPP shut down

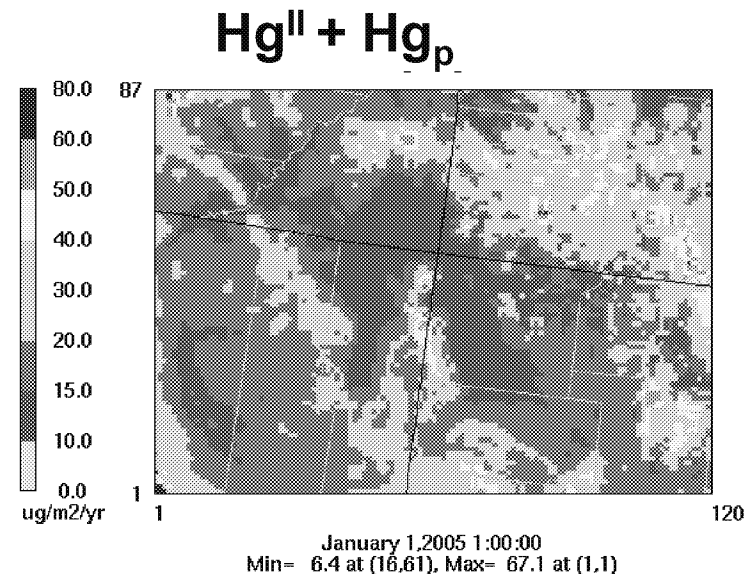
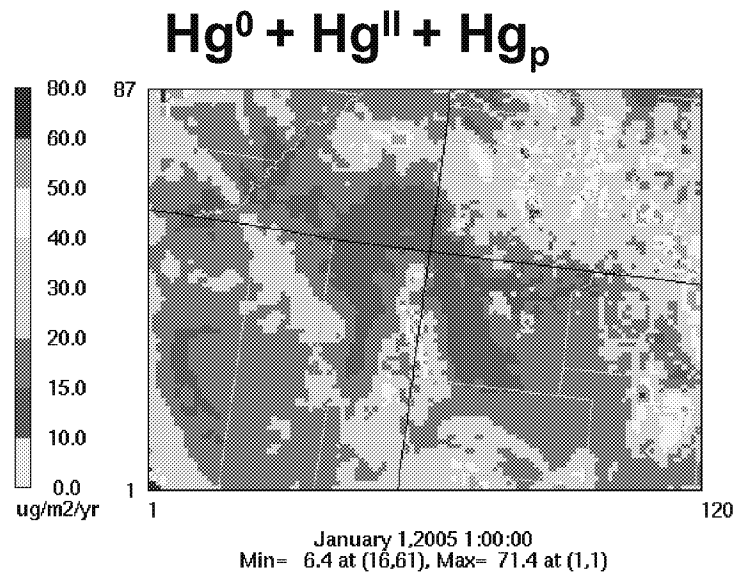
❑ Navajo Generating Station

- 1990 – 2015: 3 units operational with pre-MATS controls
 - Hg = 472 lb/yr, As = 259 lb/yr, Se = 4370 lb/yr
- 2016 – 2044: 3 units operational with post-MATS controls
 - Hg = 228 lb/yr, As = 259 lb/yr, Se = 4370 lb/yr
- 2045 – 2074: NGS shut down

❑ San Juan Generating Station

- 1990 – 2015: 4 units operational with pre-MATS controls
- 2016 – 2074: 4 units operational with post-MATS controls

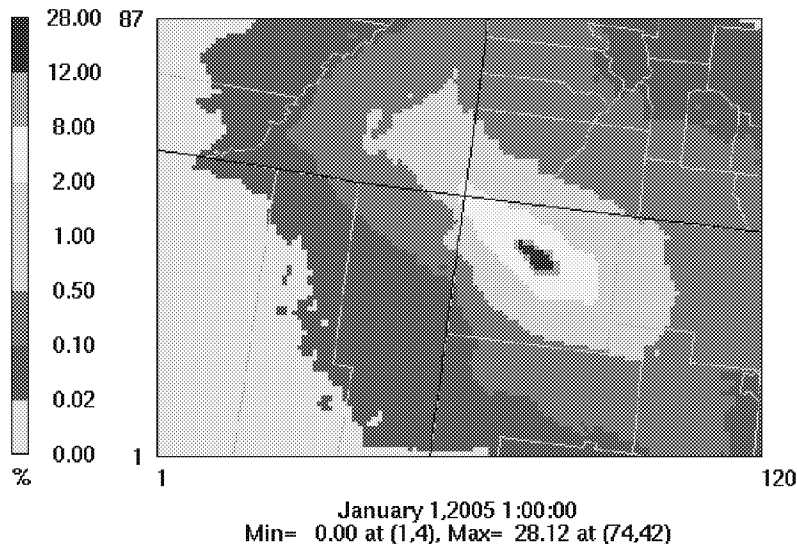
Annual wet + dry Hg deposition in baseline case



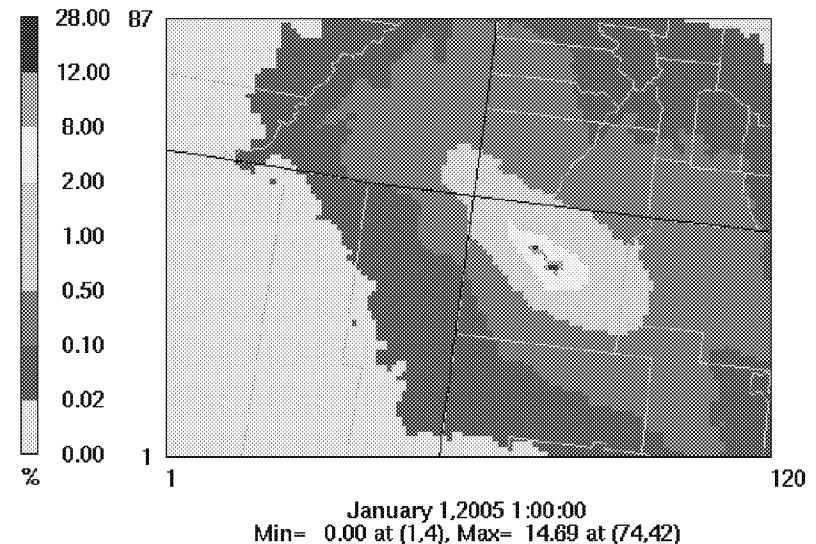
- $\text{Hg}^{\text{II}} + \text{Hg}_p$ deposition > 90% of total deposition of all forms of Hg
- Dry deposition of $\text{Hg}^{\text{II}} + \text{Hg}_p$ typically > 70% of dry + wet deposition
- Model compares well with observations at Mesa Verde National Park
 - Wet deposition within 14% of MDN measurements (under-prediction)
 - Dry deposition within 34% of EPA measurements (over-prediction)
 - Total deposition within 11% (over-prediction)
- Average Hg deposition over San Juan basin $\sim 20 \mu\text{g}/\text{m}^2/\text{yr}$
- Subsequent discussion focuses on $\text{Hg}^{\text{II}} + \text{Hg}_p$ (main forms of Hg that methylate)

Contribution of Four Corners Power Plant to mercury deposition, baseline & post-MATS cases

Baseline



Post-MATS

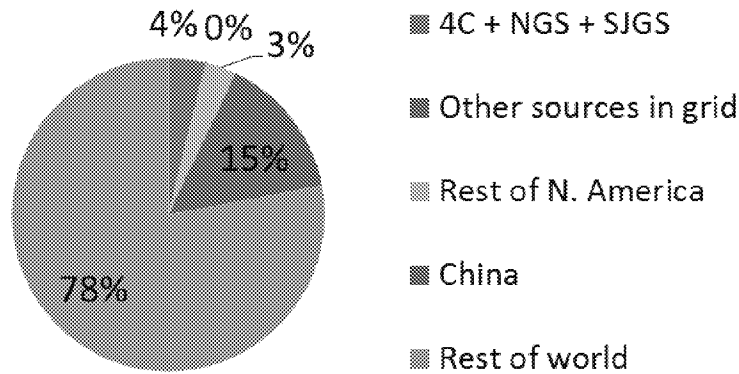


- In baseline case, FCPP contributes < 2% of total Hg deposition over most of the San Juan basin and up to 28% near the plant
- After retirement of units 1-3, FCPP contributes < 2% over most of the San Juan basin and up to 15% near the plant

Relative contribution of mercury sources to deposition at receptor locations, baseline case

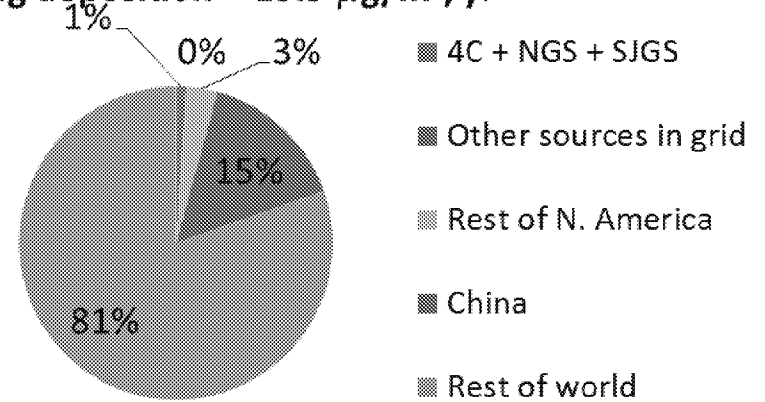
Lake Powell, AZ

Hg deposition = $13.3 \mu\text{g}/\text{m}^2/\text{yr}$



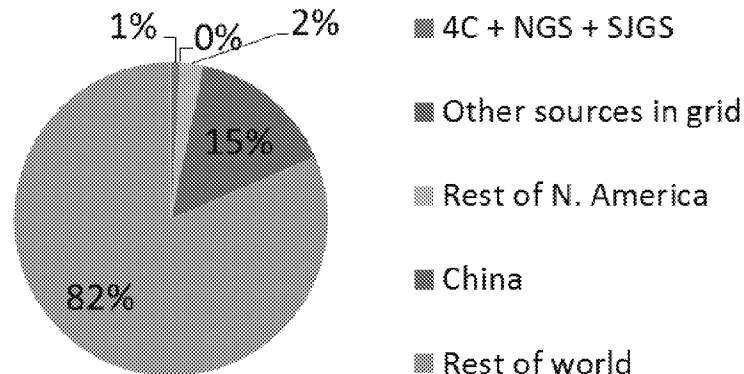
Lake Powell, UT

Hg deposition = $13.9 \mu\text{g}/\text{m}^2/\text{yr}$



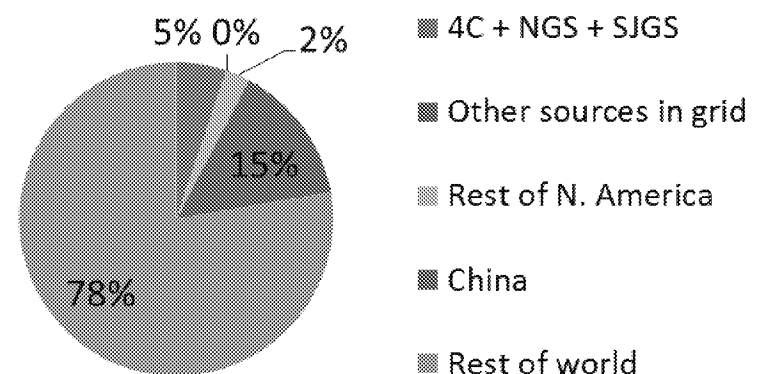
Navajo Lake, NM

Hg deposition = $14.2 \mu\text{g}/\text{m}^2/\text{yr}$



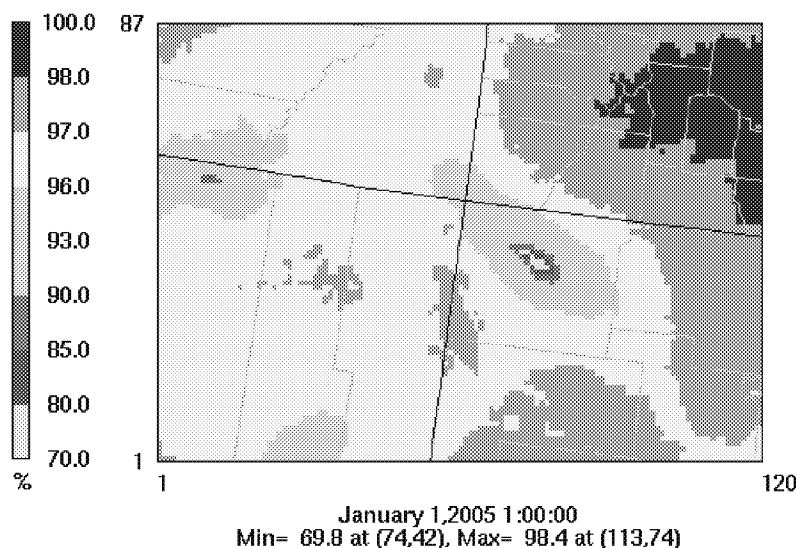
Shiprock, NM

Hg deposition = $16.5 \mu\text{g}/\text{m}^2/\text{yr}$

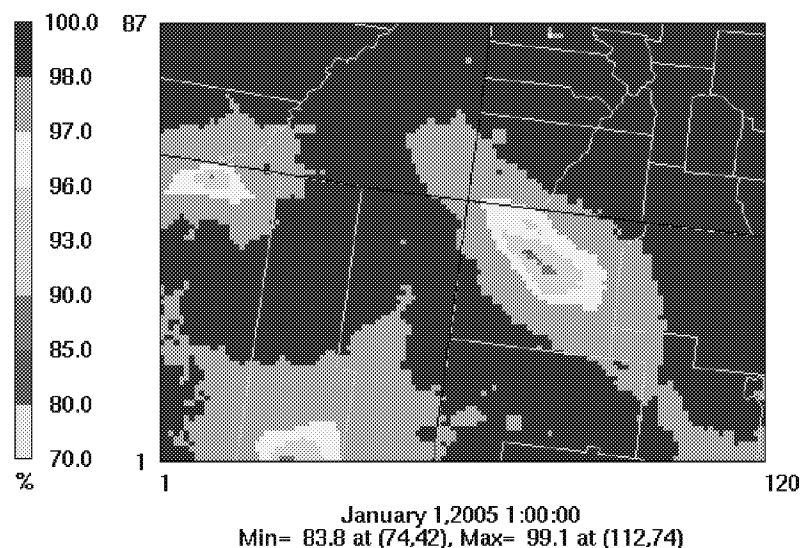


Contribution of non-US sources to mercury deposition in baseline and post-MATS cases

Baseline



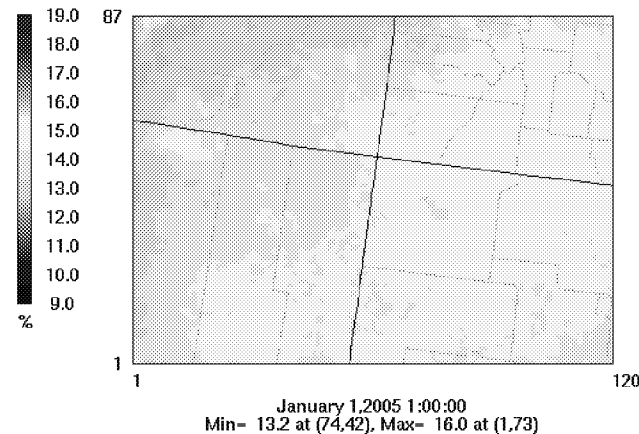
Post-MATS (2016 emissions)



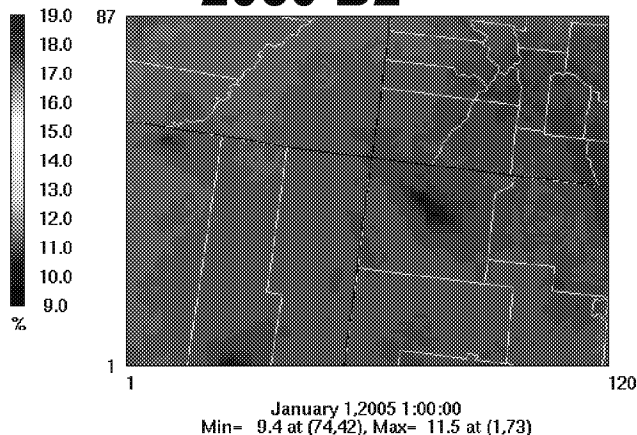
- In baseline case, non-US sources contribute at least 69% of total Hg deposition everywhere in the San Juan basin
- After 2016, non-US sources contribute at least 83% of total Hg deposition everywhere in the San Juan basin (higher than baseline due to reductions in US power plants and other sources)

Contribution of Chinese sources to mercury deposition in post-MATS, 2050 A2, 2050 B2 cases

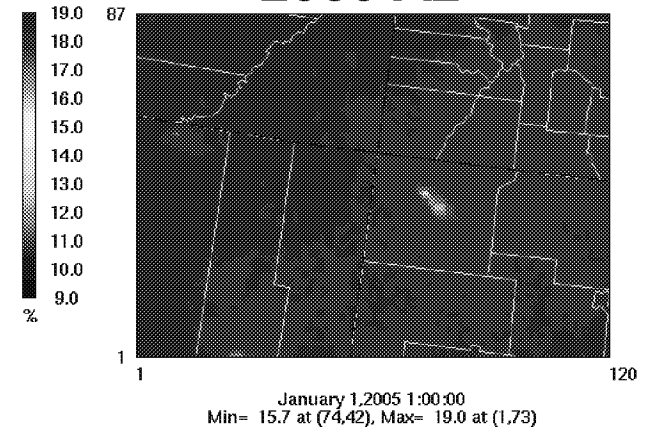
Baseline



2050 B2

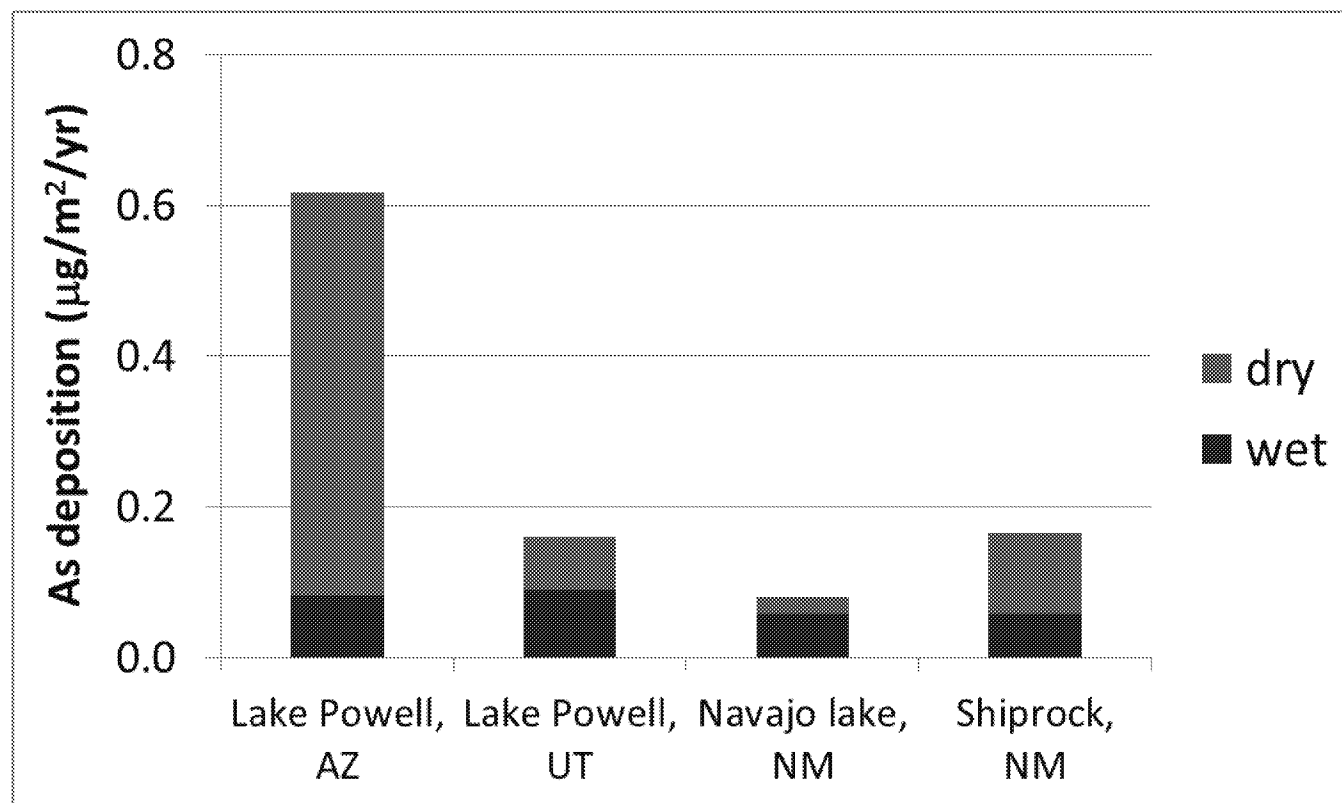


2050 A2



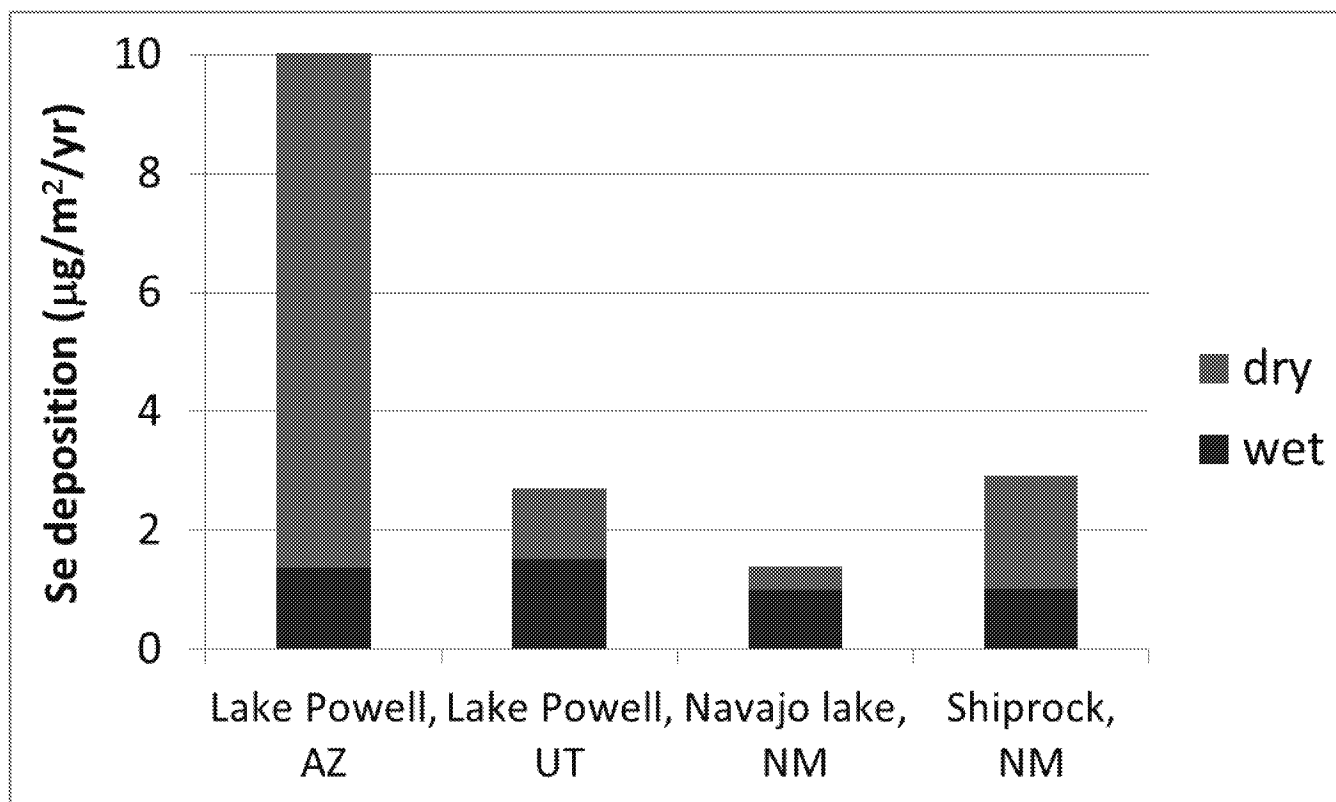
- Chinese sources contribute up to 12% of total Hg deposition in low China case, up to 16% in baseline and up to 19% in high China case

Arsenic deposition due to the three local power plants at four receptor locations in baseline case



- Either dry or wet deposition could dominate depending on location
- Limited measurements of total arsenic deposition in USA
 - Dry + wet measured As deposition = 101 to 703 $\mu\text{g}/\text{m}^2/\text{yr}$ along the mid-Atlantic coast (Scudlark et al., 1998) and

Selenium deposition due to the three local power plants at four receptor locations in baseline case



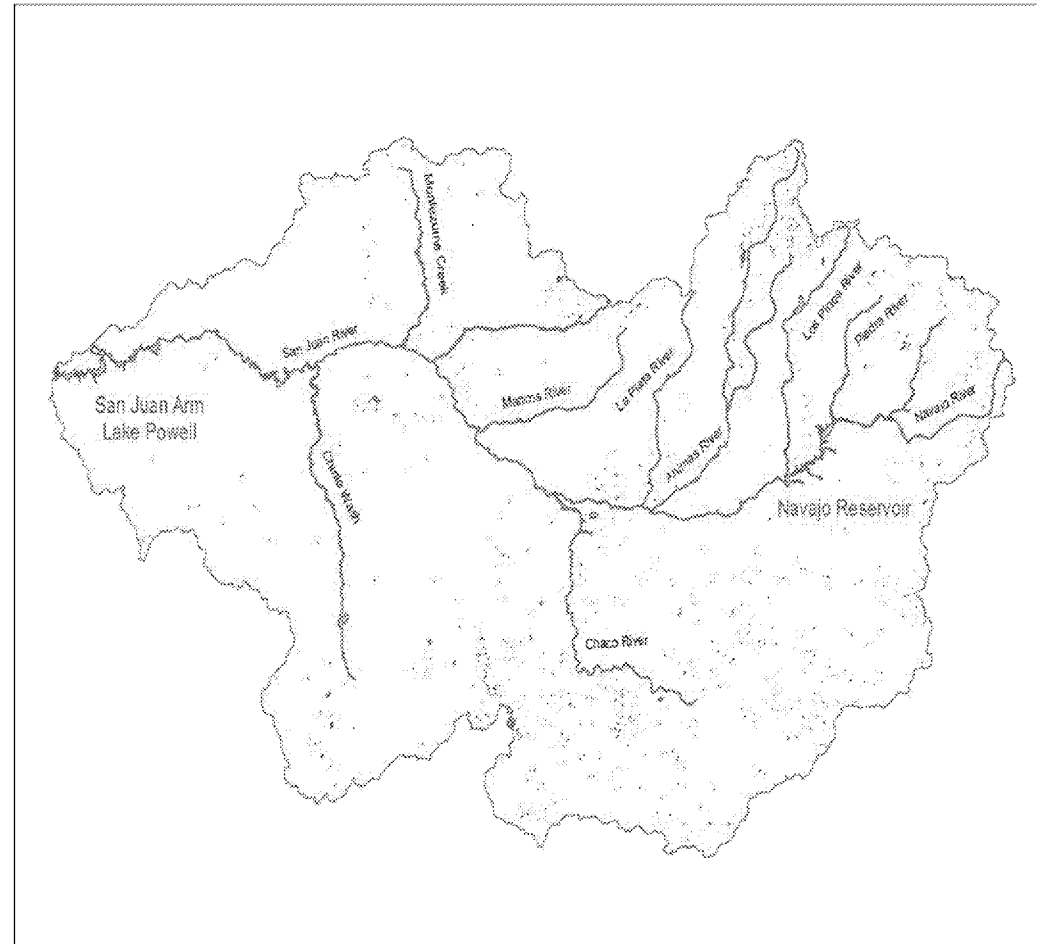
- Either dry or wet deposition could dominate depending on location
- Limited measurements of total selenium deposition in USA
 - Measured dry + wet selenium deposition = $45 \mu\text{g}/\text{m}^2/\text{yr}$ in Delaware (Wen and Carignan, 2007)

Watershed and Ecosystem Modeling

Joel Herr
Systech

Project Area

- 25, 000 square miles / 16 million acres
- Three coal-fired power plants
- Multiple surface reservoirs
- Critical habitat for endangered fish

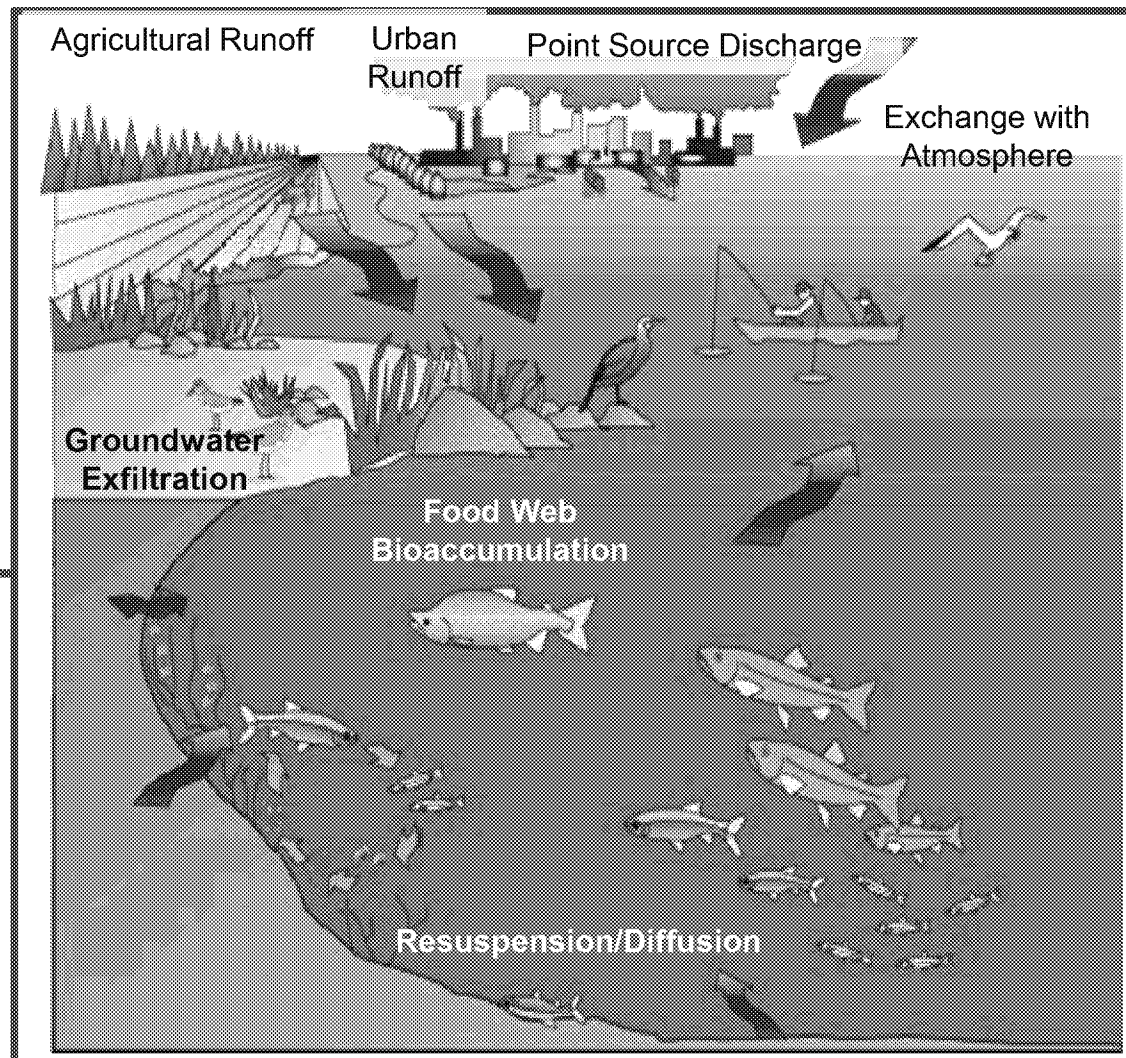


GEOS-Chem/CMAQ-APT Models

Atmospheric Emissions

Atmospheric Deposition

**WARMF
Model**

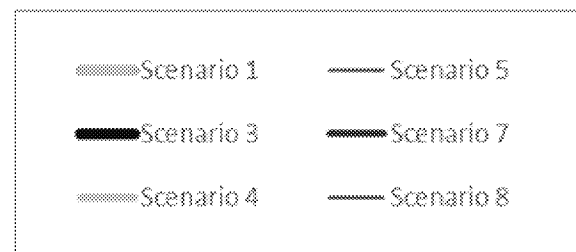
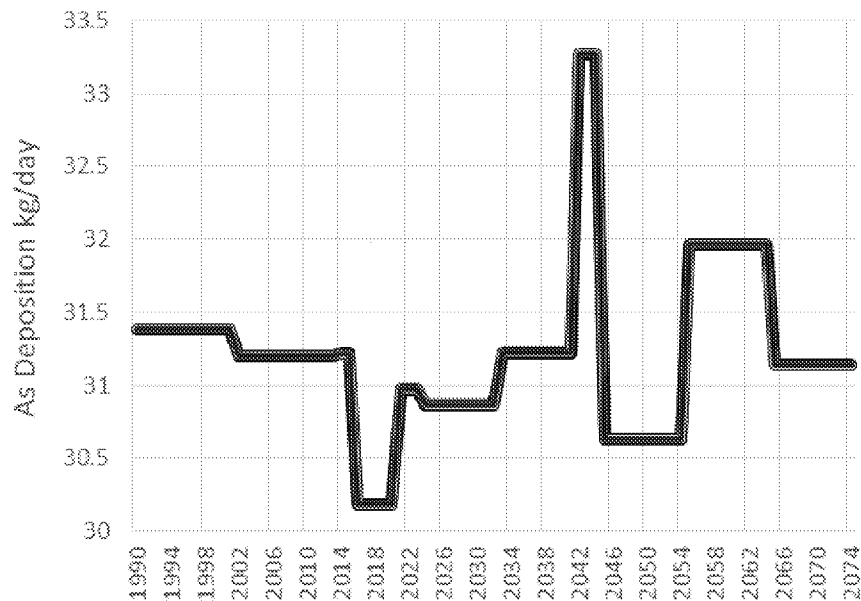
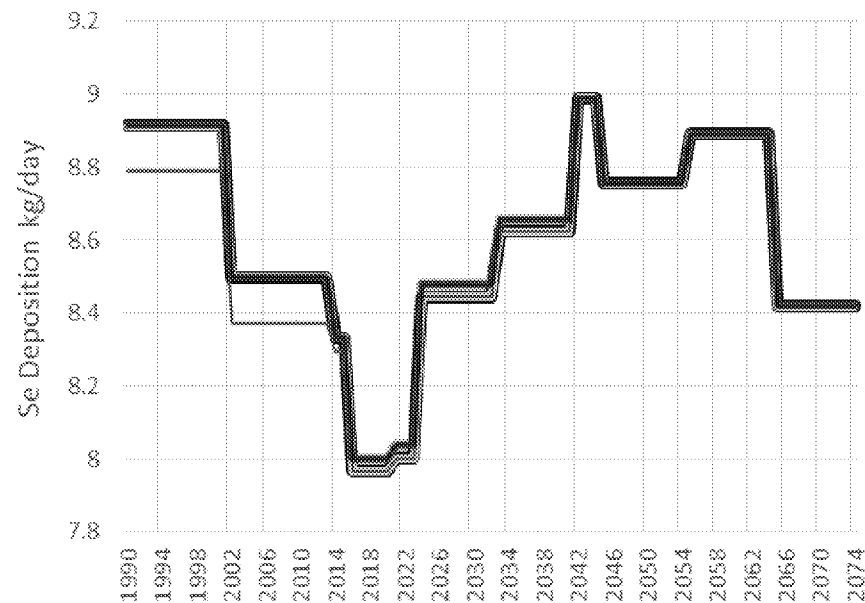
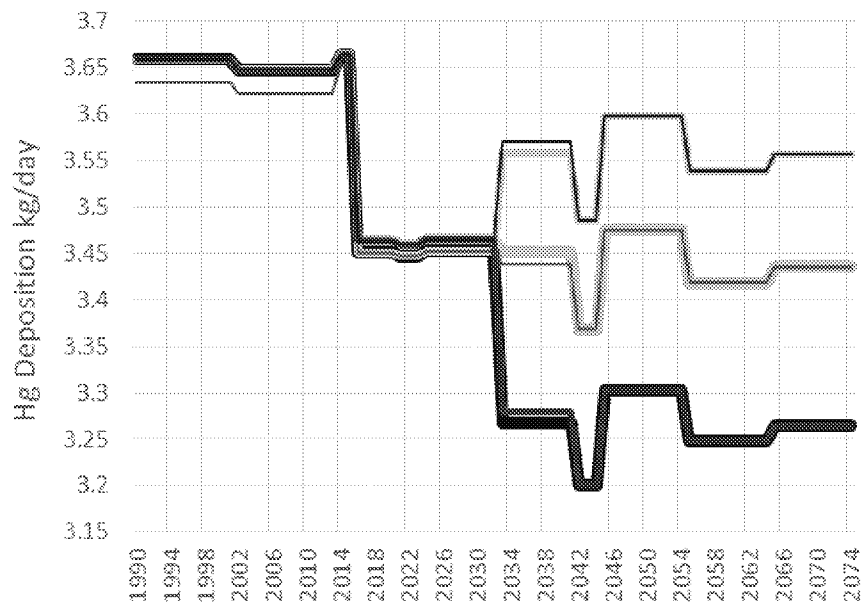


Simulation Details

- Dynamic simulation run on daily time step
- Maintains volume, mass, heat balances
- Hydrologic parameters simulated:
flow, depth, velocity, surface elevation, snow pack depth, evaporation/transpiration
- Water quality parameters simulated
temperature, pH, ions (Ca, Mg, K, Na, SO₄, Cl, TIC), nutrients (NH₄, NO₃, PO₄, TKN, TN, TP), DO, organic carbon, suspended sediment, phytoplankton, mercury, metals

6 WARMF Model Scenarios, 1990-2074

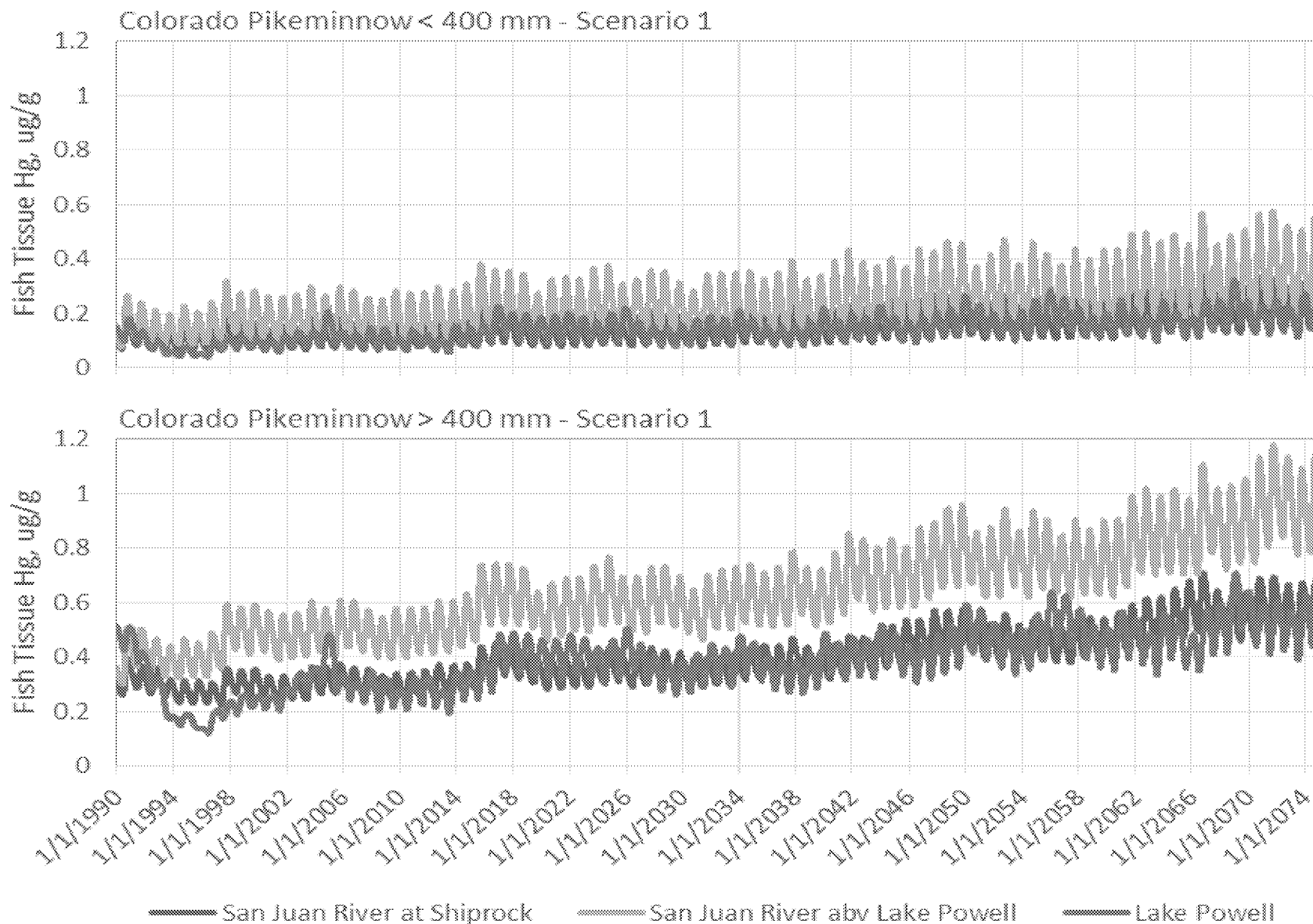
| Scenario Name | Four Corners Power Plant | Chinese Emissions |
|----------------------------------|---------------------------|--|
| Arizona Public Service (APS) - 1 | Base Case – 2042 Shutdown | Base Case - constant |
| APS – 3 | 2016 Shutdown | Low Growth Emissions (deposition in U.S. drops) |
| APS – 4 | 2016 Shutdown | High Growth Emissions (deposition in U.S. grows) |
| APS – 5 | Never Existed | Base Case - constant |
| APS – 7 | Base Case – 2042 Shutdown | Low Growth Emissions (deposition in U.S. drops) |
| APS – 8 | Base Case – 2042 Shutdown | High Growth Emissions (deposition in U.S. grows) |

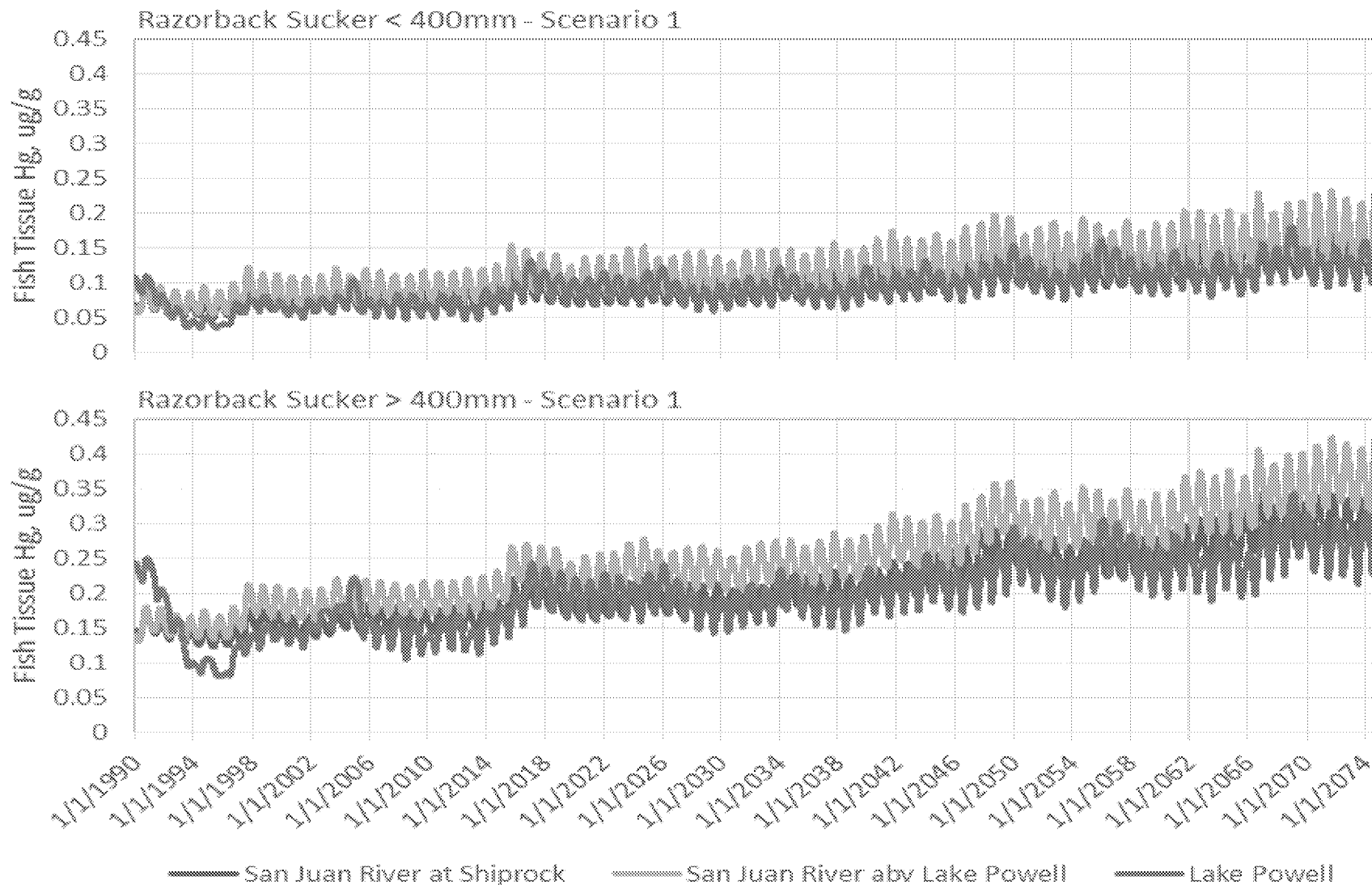


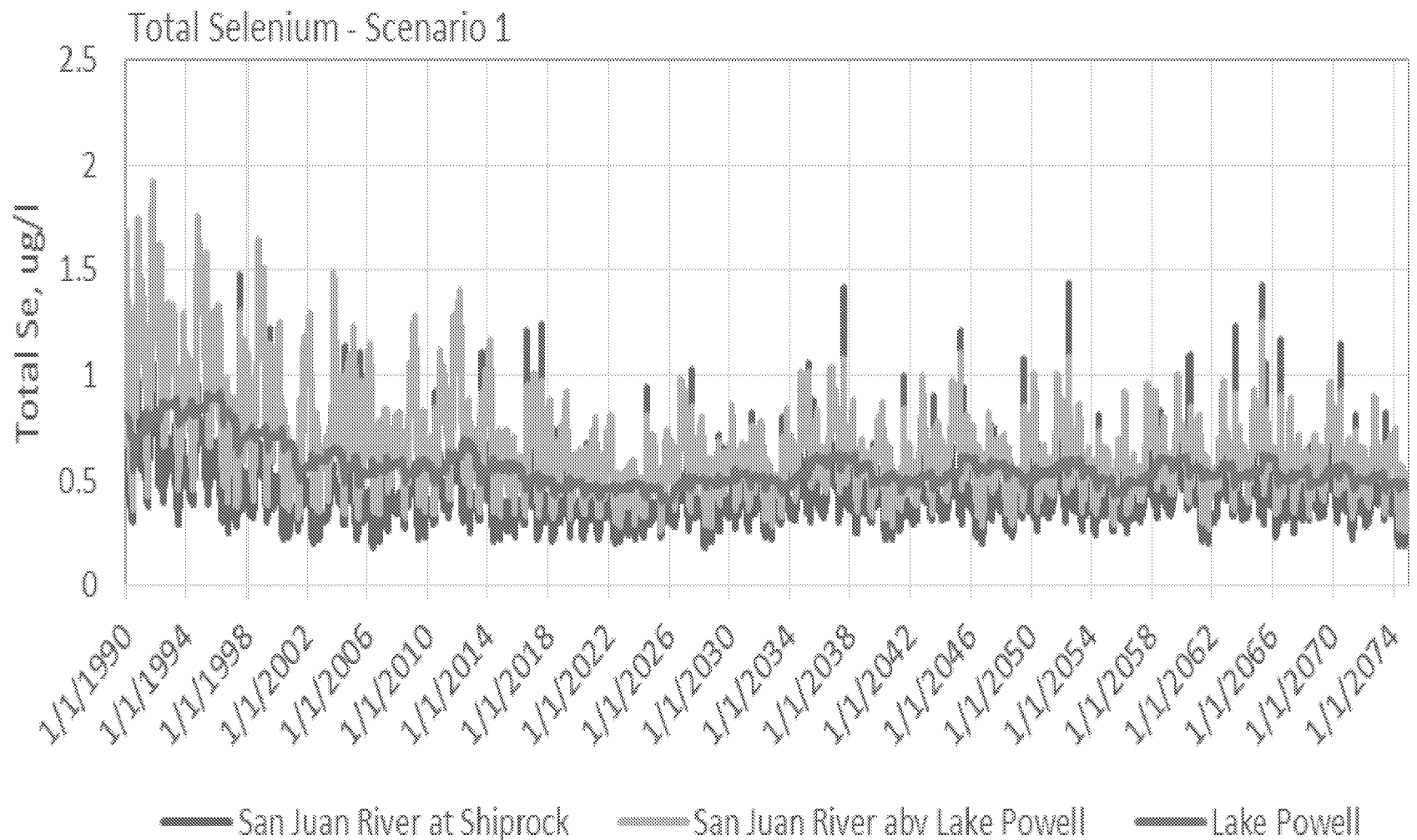
Average Atmospheric Deposition to the Watershed

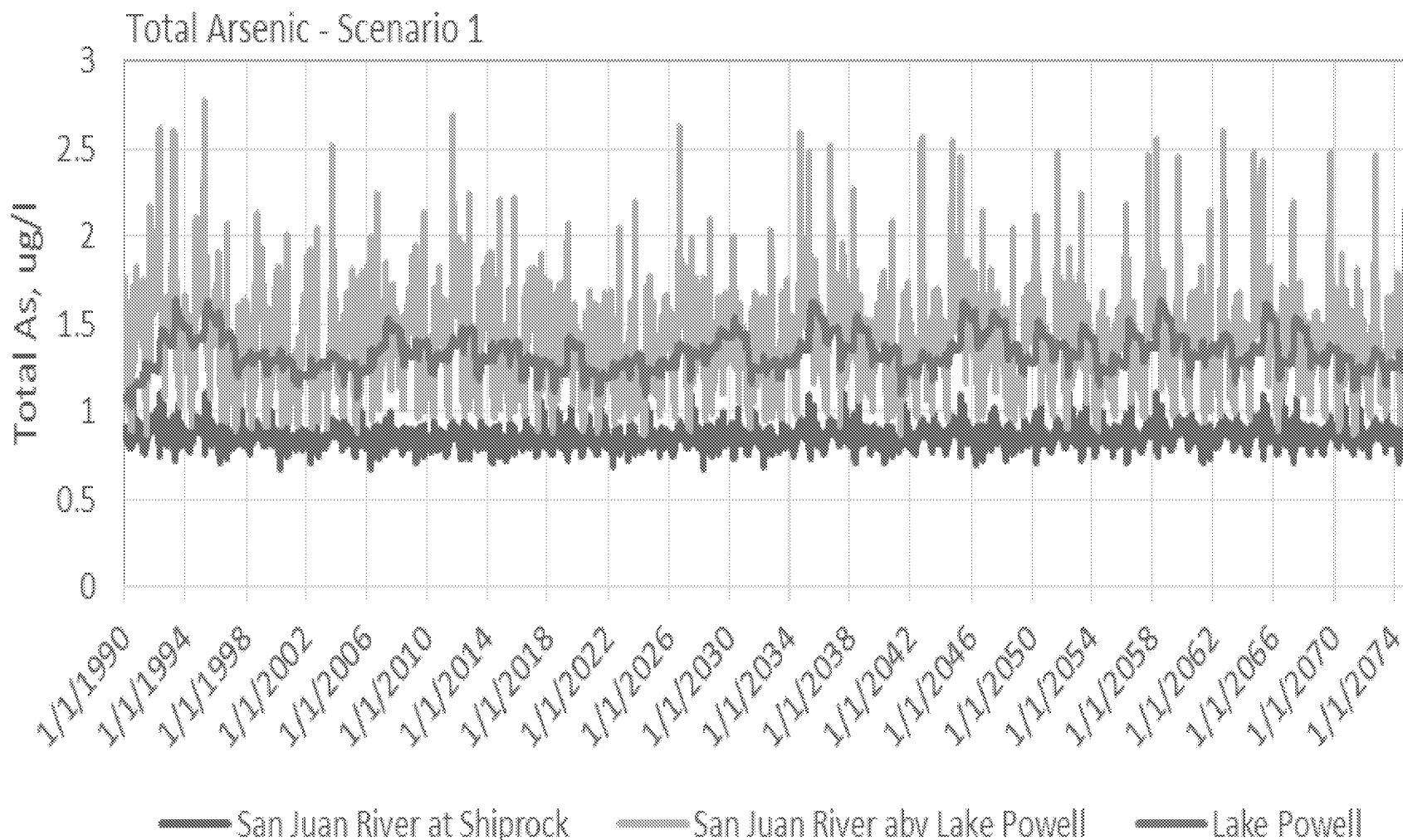
Projected Future Fish Tissue Mercury Concentrations

- Simulations are for period 1990-2074
- Base case expected future conditions (scenario 1)
- Less than 1% of annual mercury atmospheric deposition ends up in San Juan River/Lake Powell
 - Loss to evasion (back to the atmosphere)
 - Large watershed/waterbody ratio
 - Soil sequestration (accumulation)
- Historical data insufficient to detect trend
 - Model's trend prediction is uncertain
- Future deposition is uncertain









Scenario Comparisons

| Comparison Case | Base Case | Differing Condition | Common Condition |
|-----------------|-----------|--|-------------------------------|
| APS – 5 | APS – 1 | 2042 FCPP Shutdown vs. Never Existing | Base Case Chinese Emissions |
| APS – 7 | APS – 1 | Base Case vs. Low Growth Chinese Emissions | 2042 FCPP Shutdown |
| APS – 8 | APS – 1 | Base Case vs. High Growth Emissions | 2042 FCPP Shutdown |
| APS – 3 | APS – 7 | 2016 vs. 2042 FCPP Shutdown | Low Growth Chinese Emissions |
| APS – 4 | APS – 8 | 2016 vs. 2042 FCPP Shutdown | High Growth Chinese Emissions |

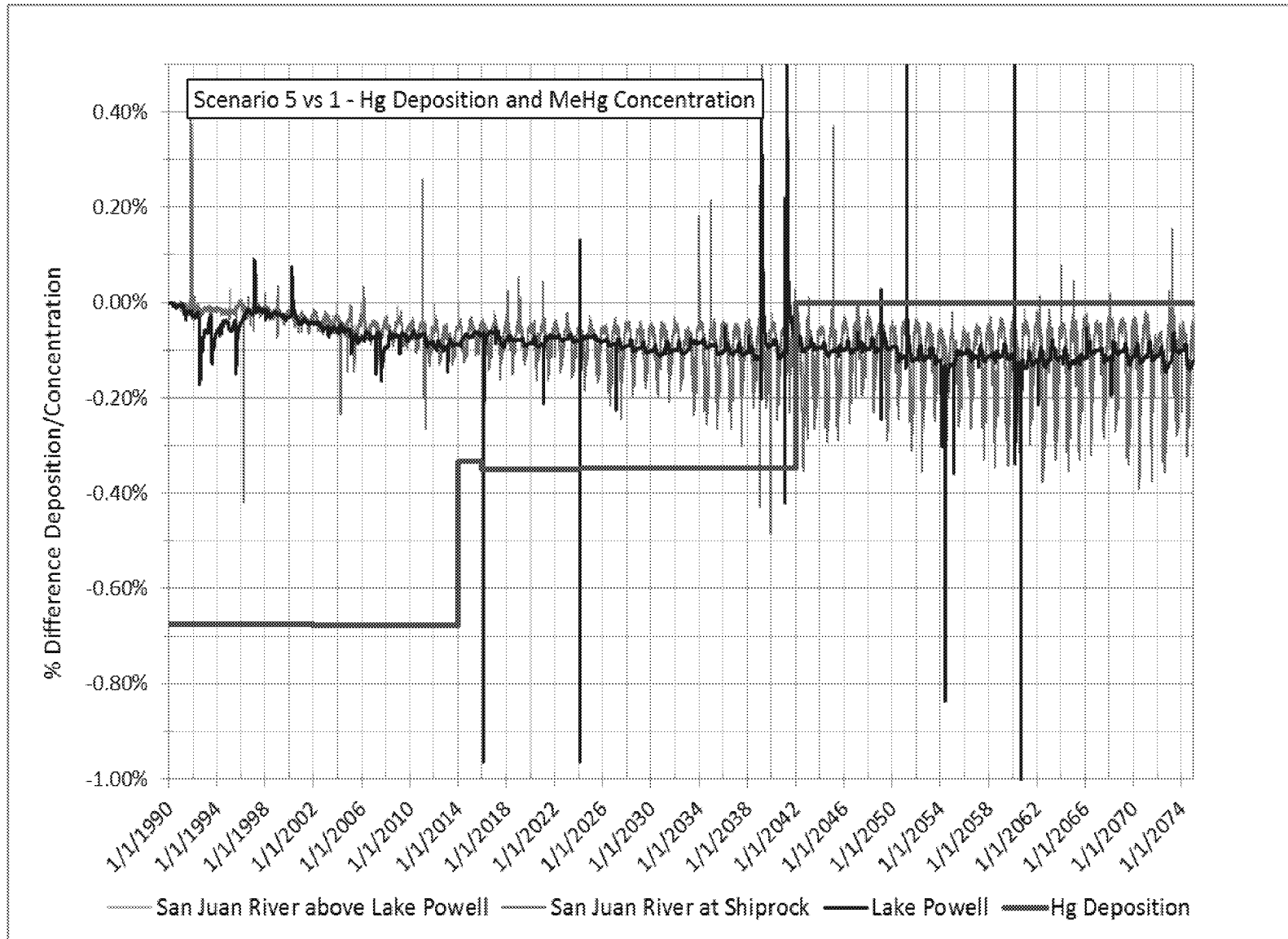
APS-5 versus APS-1 Results: Mercury

**Common
Condition**

Mid-range
Chinese
Emissions

**Differing
Condition**

2042 FCPP
Shutdown
vs. Never
Existing



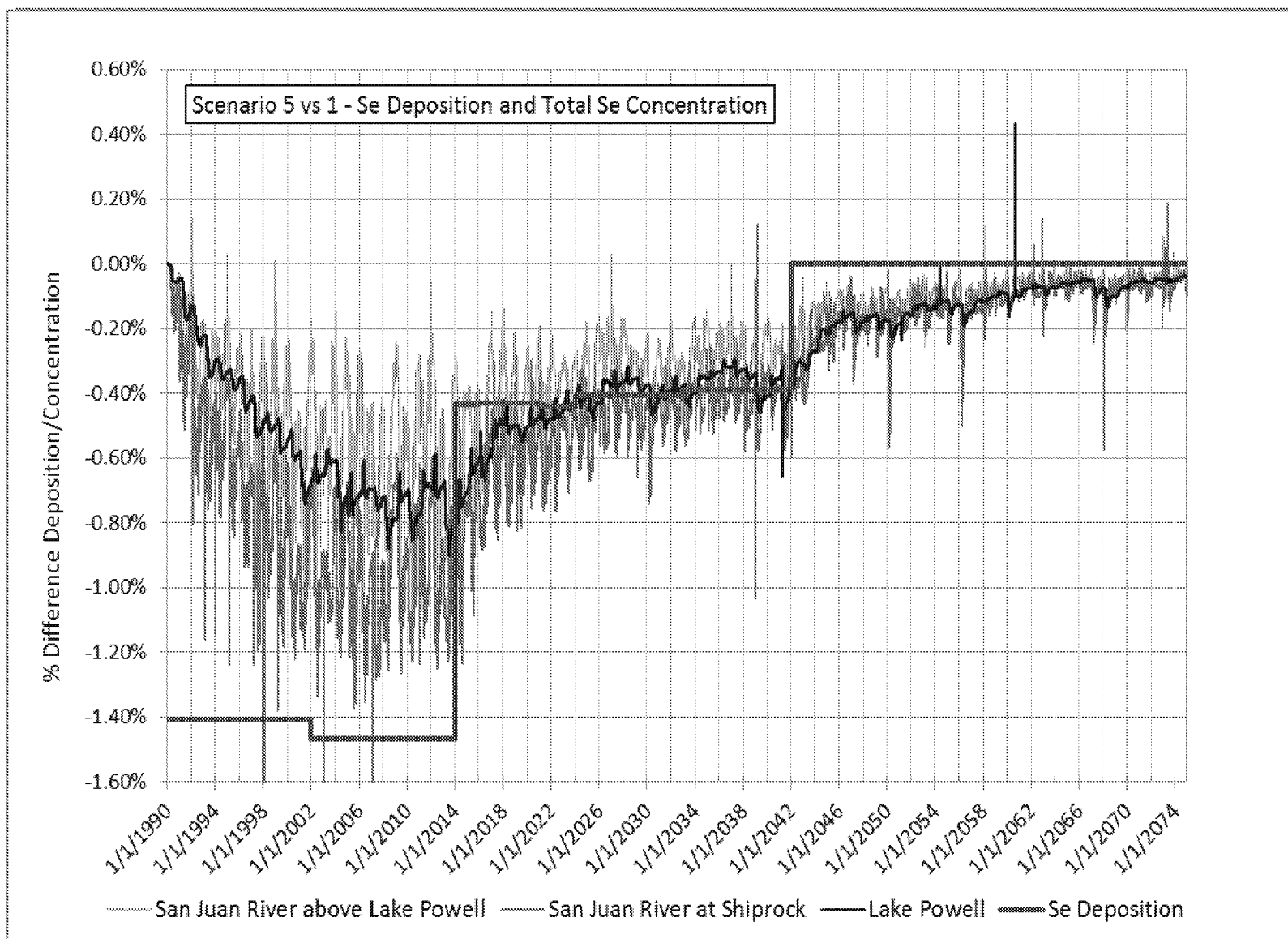
APS-5 versus APS-1 Results: Selenium

**Common
Condition**

Mid-range
Chinese
Emissions

**Differing
Condition**

2042 FCPP
Shutdown
vs. Never
Existing



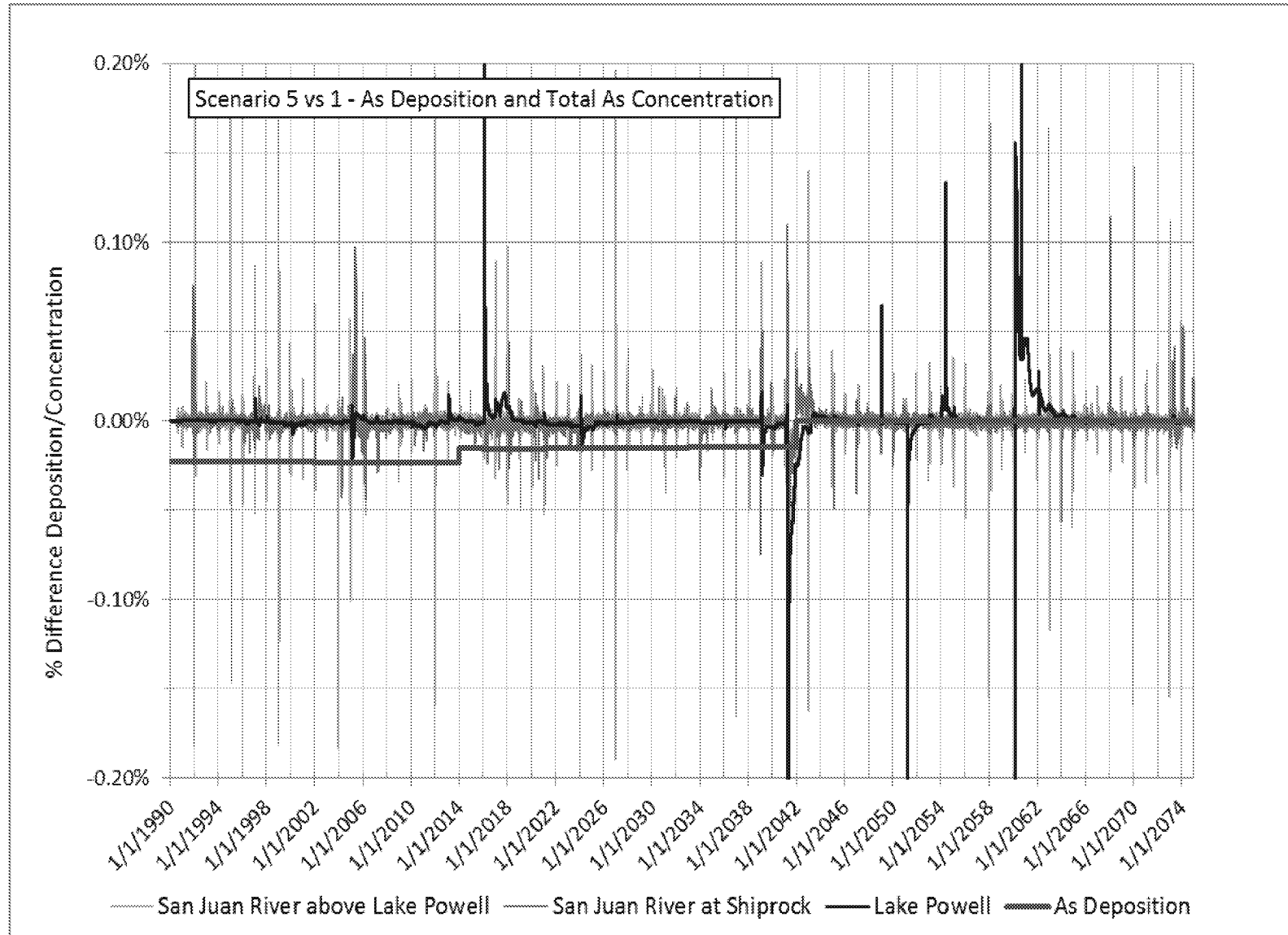
APS-5 versus APS-1 Results: Arsenic

**Common
Condition**

Mid-range
Chinese
Emissions

**Differing
Condition**

2042 FCPP
Shutdown
vs. Never
Existing



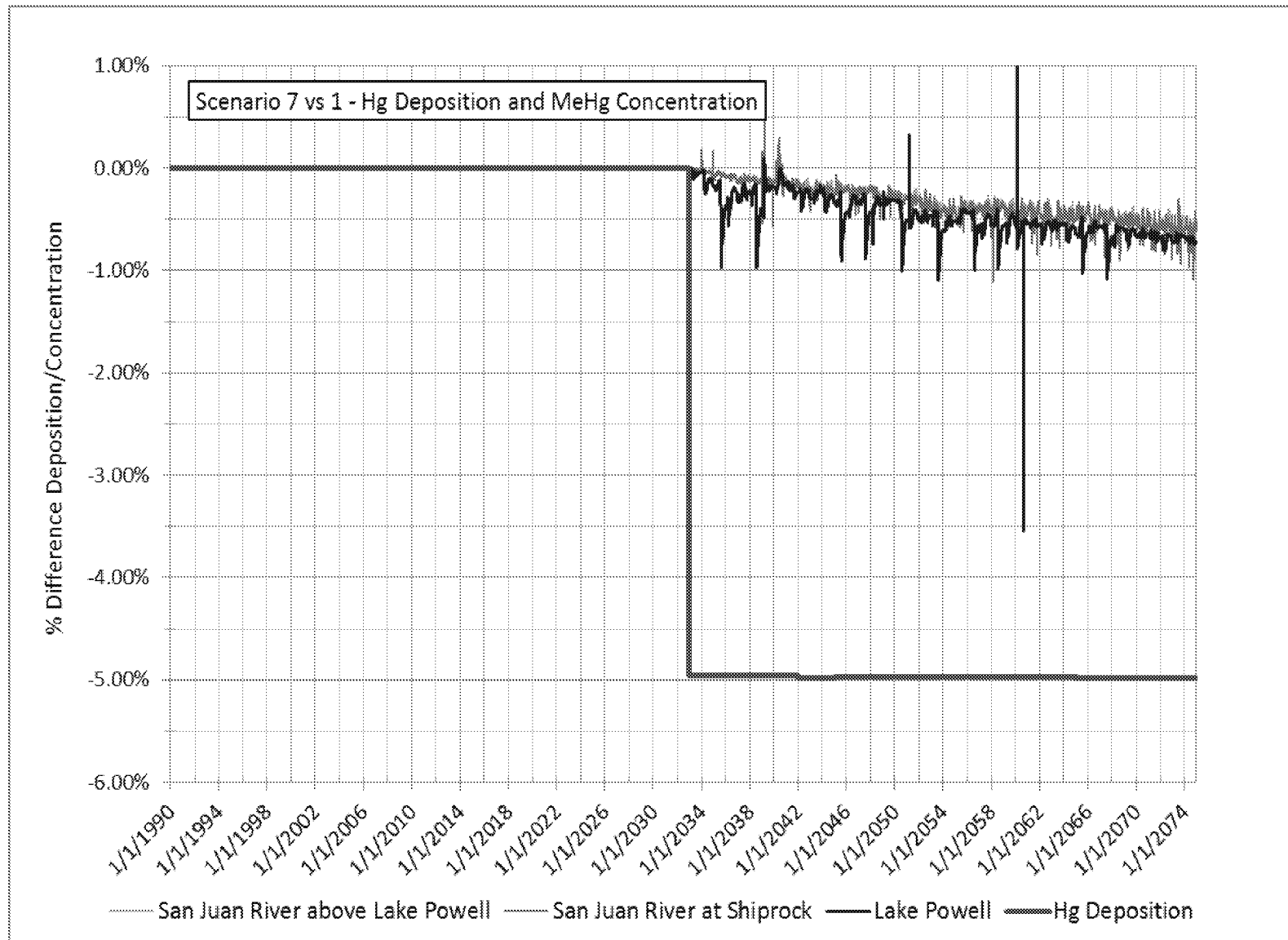
APS-7 versus APS-1 Results: Mercury

**Common
Condition**

2042 FCPP
Shutdown

**Differing
Condition**

Mid vs. Low
Chinese
Emissions



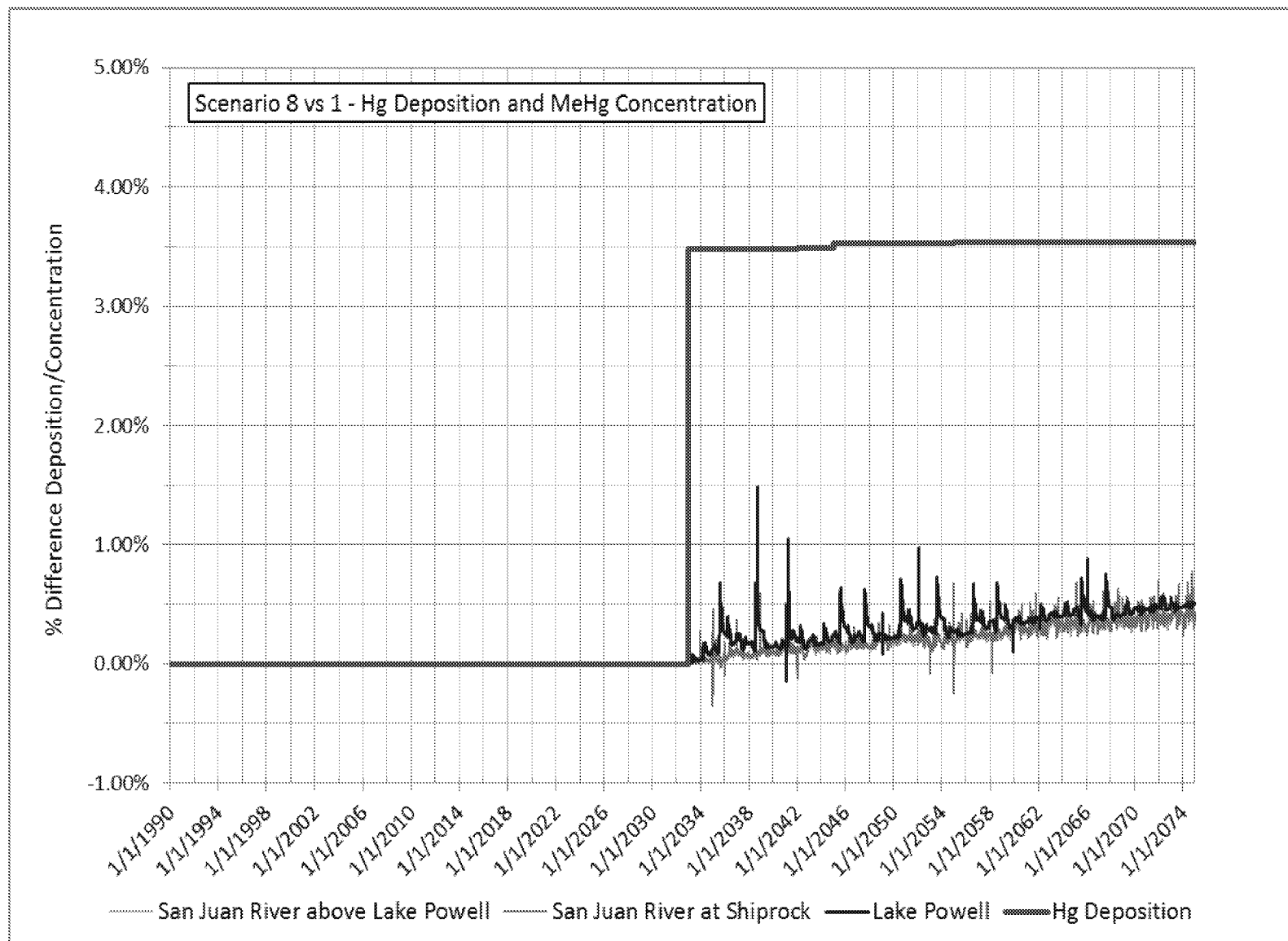
APS-8 versus APS-1 Results: Mercury

**Common
Condition**

2042 FCPP
Shutdown

**Differing
Condition**

Mid vs.
High
Chinese
Emissions



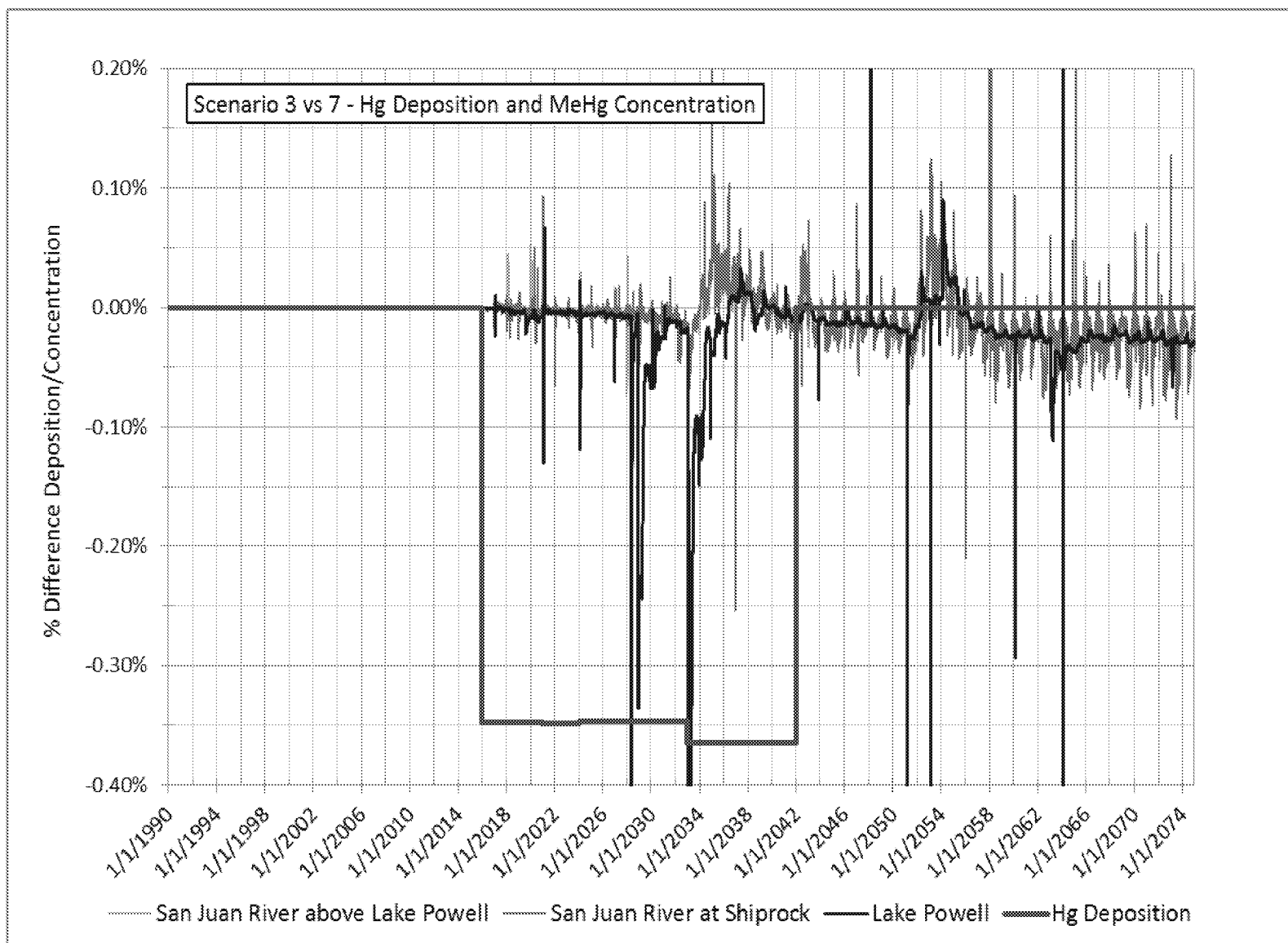
APS-3 versus APS-7 Results: Mercury

Common
Condition

Low
Chinese
Emissions

Differing
Condition

2016 vs.
2042 FCPP
Shutdown



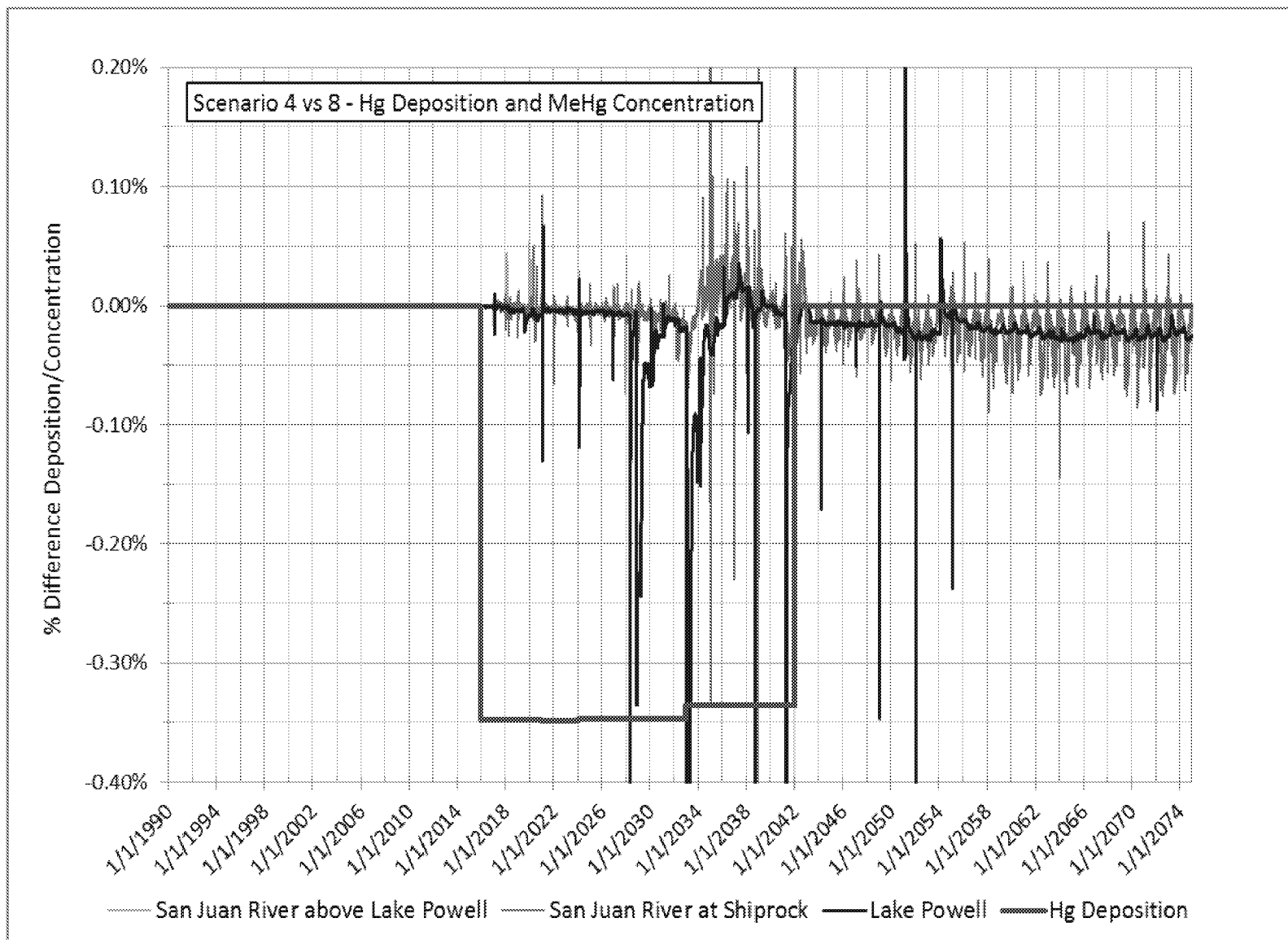
APS-4 versus APS-8 Results: Mercury

**Common
Condition**

**High
Chinese
Emissions**

**Differing
Condition**

**2016 vs.
2042 FCPP
Shutdown**



Conclusions: Model Application

- Linkage between CMAQ-APT and WARMF predicts watershed response to air emissions changes
- Linkage can be used to evaluate future conditions, effects of management decisions
- Future trend is highly uncertain
 - Not enough data to discern historical trend, adjust model calibration
- Model has more predictive power when comparing conditions between scenarios (relative changes)

Conclusions: Simulation Results

- **Effect of Four Corners Power Plant (FCPP) operations:**
 - Mercury
 - <1% of total deposition* is due to FCPP emissions
 - Watershed & biota responses to changes in emissions & deposition take decades to fully realize
 - Selenium
 - Deposition: >1% currently/<1% after 2015 is due to FCPP
 - Watershed response to changes is more rapid
 - Arsenic
 - <0.1% of deposition is due to FCPP
 - Watershed response almost indiscernible
- **Outcomes can be viewed as “central estimates”** with relatively large uncertainties; limit: lack of long-term observations in SJB

* Figures are for watershed averages

QUESTIONS?

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